Improved condition assessment of XLPE insulated cables using the isothermal relaxation current technique

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Abstract: Well-known procedures using the isothermal relaxation current method (IRC) use an empirically-derived ageing factor (the A-factor) to estimate the condition of cables. The A-factor is calculated from plots of the product of instantaneous value of IRC and the time to that value from the start of the current, against the log of time. A-factors are computed from a standard formula using constants determined from curve fits of measured depolarization currents.
From measurements of the breakdown strength of samples of real and degraded cables it has been found that A-factors do not provide reliable estimates of XLPE cable condition. However, if semi-conducting material of the cable insulation is known and cables are classified according to semi-conducting material type it is possible to get better correlation between conditions of cables as indicated by A-factors and AC breakdown voltage. This paper contains a novel analysis of result from previous researcher and also includes result from tests on other cables. The refined procedure is found to give reasonable value of A-factor for all cable tested.

Introduction

Depolarization current method to wit the isothermal relaxation current method of assessing the condition of power cable insulation has been in use for more than 10 years. Tested cable samples are mainly from German manufacturer and were found to contain mostly bow-tie water tree [1]. The outer semi-conducting layer of tested samples were made of graphite/extruded. For the cases studied, good correlation is found between AC-steptest performed according to German standard (DIN VDE) and non-destructive IRC analysis [1, 2].

The characteristic aging factor known as A-factor determined by IRC analysis is said to described the aging process best, because as the A-factor increases with increase in aging time, the AC step-test decreases with aging time [1,2]. This forms the fundamental diagnostic criteria upon which the IRC analysis is based.

Specificity of presentation

In the analysis the measured depolarization current is descried as sum of a quasi-dc current that is often referred to a constant current I_0 (because of it's slow rate of decay in time) and three exponential functions with different relaxation time τ given by

$$i(t) = I_0 + \sum_{i=1}^{3} a_i e^{-t/\tau_i} \qquad (1)$$

Where the parameters a_i and τ_i are correlated with the material properties. The time constant τ_3 is related to water degradation of the cable insulation.

An empirical ageing factor (A-factor) is calculated to classify the ageing condition of the cable. This factor is calculated from the depolarization current I_D at time constant τ_3 and τ_2 as

$$A = \frac{I_D(\tau_3)\tau_3}{I_D(\tau_2)\tau_2} \qquad (2)$$

Nowadays, IRC-analysis is performed with software tool that allows fully automatic non-destruction determination of the ageing status without any reference measurements by analyzing the data with well adapted artificial neural networks [3-5]. In the new software approach for correct analysis of measured data detailed knowledge of cable construction is necessary. However, this software analysis is not available in the IRC test system used in the present studies. Also it is possible that such software is not available in previous IRC test system which is still in used today by many utilities.

In order to convert our existing diagnostic data acquired with the IRC test system to useful information, results of similar measurements were gathered and classified by semi-conducting material type in use. Approximated curve is found that relate the A-factor and the residual strength prognosis (RSP). This is applied to practical case as will be demonstrated later in this paper.

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Results and analysis

Figure 1 shows the correlation between AC Break down (ACBD) voltage and A-factor for all insulation type combined. Splitting Figure 1 according to semi-conducting material type we have Figures 2-4. These figures present the correlation between the lowest ACBD voltage and the A-factor for insulation type considered separately. One will notice that no correlation exist in Figure 1. However, though to some extent certain correlation can be seen in Figures 2-4. This shows the importance of semi-conducting material type of insulation used in cable under investigation.

In addition, one can conclude that water tree initiation and propagation is different for different semi-conducting material and hence different water tree length. What might be of interest is to plot the water tree length vs ACBD voltage and water tree length vs A-factor to see if there is correlation.

Figures 2-4 indicate that A-factor increases with ACBD voltage. Though this increase is fairly shown due to scatter result however, it is the opinion of the author that if A-factor and ACBD voltage is classified in accordance with the semi-conducting type. This classification could be used for assessing the condition state of the insulation. However, IRC analysis is based on the principle that the higher the A-factor the lower the breakdown voltage.

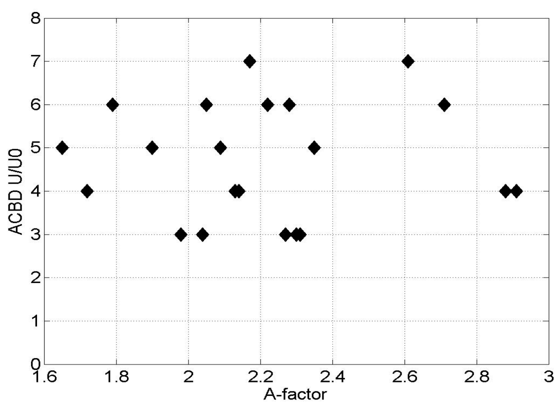

Figure 1: Poor correlation between ACBD U/U_0 and A-factor. Data after [6]

Figures 5-7 represent the correlation of A-factor and residual strength prognosis corresponding to Figures 2-4. It is important to mention that Figures 5-7 are obtained from the Seba Dynatronic comments in response to Figure 1 from where Figures 2-4 are obtained [6]. In this case as A-factor increases the RSP decreases as shown in the figures that follows. This is the principle on which IRC analysis is based. So, cables could be classified according to the type of their semiconductors.

It is anticipated that water tree length that determines the minimum breakdown strength of the insulation is independent of the semi-conducting material but it may depend on the cable construction.

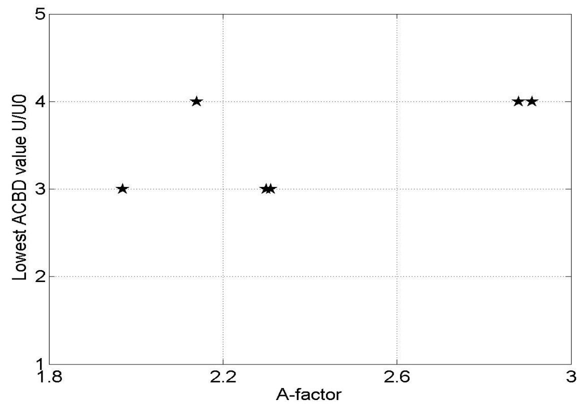

Figure 2: ACBD vs A-factor for paint and tape semi-conducting type.

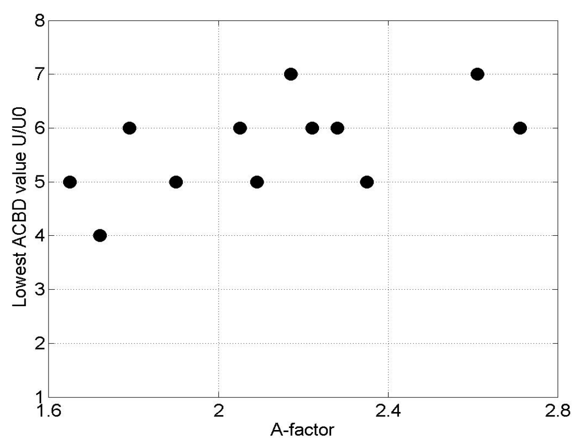

Figure 3: ACBD vs A-factor for Strippable tape semi-conducting type. Data after [6]

The classification by semi-conducting type method discussed earlier is at this point implemented on more cables with strippable semi-conducting material as shown in Figure 8 from where it can be shown that there is no correlation between the ACBD voltage and the A-factor. However, upon application of previously discussed approach of semi-conducting material type and RSP, a good assessment of cable condition can be achieved.

Figure 9 presents approximate curves obtained for strippable and paint and tape semi-conducting insulation type. Result of Figure 8 is presented as well for better comparison and analysis.

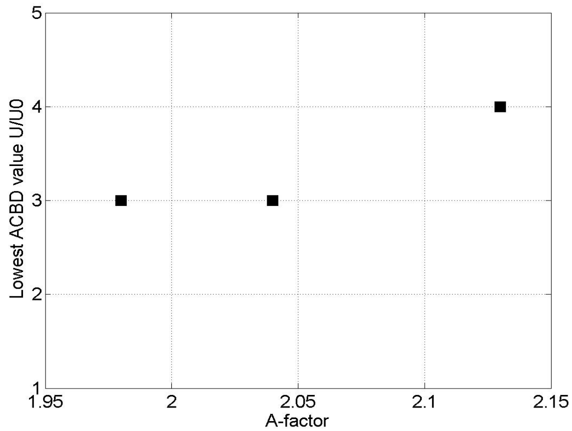

Figure 4: ACBD vs A-factor for Graphite tape semi-conducting type. Data after [6]

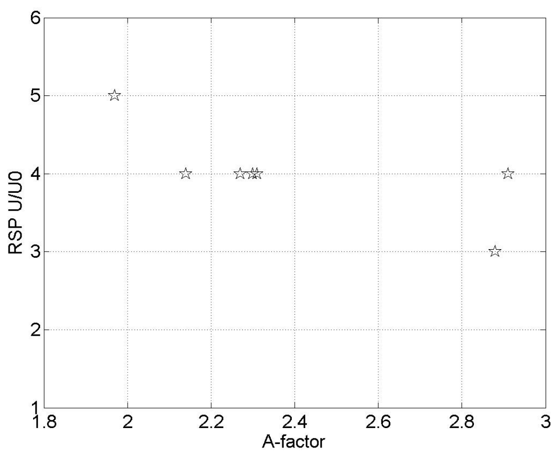

Figure 5: RSP vs A-factor according to IRC-analysis for paint and tape semi-conducting type

The A-factor and the corresponding ACBD voltage suggest that most of the cables under investigation can be diagnosed with any of two semi-conducting material curve (Strippable or paint and tape).

Whichever curve is followed for the measured data in Figure 8 the class for the insulation condition is expected to remain the same. With this done one can now apply the evaluation criteria according to IRC analysis i.e. old, mid-life, mid-life or perfect insulation provided A-factor is accurately estimated as previously discussed [7].

Referring to Figure 9 it can be seen that condition of all the cables tested except two with breakdown voltage of about $3U_0$ could be correctly assessed by A-factor. With the A-factor of these two cables around 1.9 and 2.1 it is possible that there is error calculation of A-factor [7] or perhaps the breakdown voltage of about $3U_0$ experienced on these cables is due to local degradation in form of electrical trees at a localized point and not as a result of global ageing of the cable.

Also it is possible that these cables have few but long vented water trees. This in turn suggests that the use of one criterion might not be sufficient for correct assessment of XLPE cable insulation condition.

Another concern is the time interval between the diagnostic measurement and the breakdown test. Long time period between these two tests (diagnostic and breakdown) is not desirable as water tree may dried out over time. This later reason can be ruled out since the consequence of water tree dried out is to improve the breakdown strength. Base on the work presented in this paper a preliminary guide is given in Table 1.

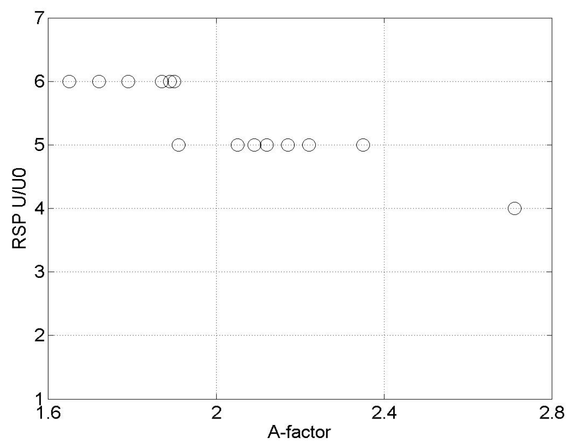

Figure 6: *RSP vs A-factor according to IRC-analysis for strippable semi-conducting type*

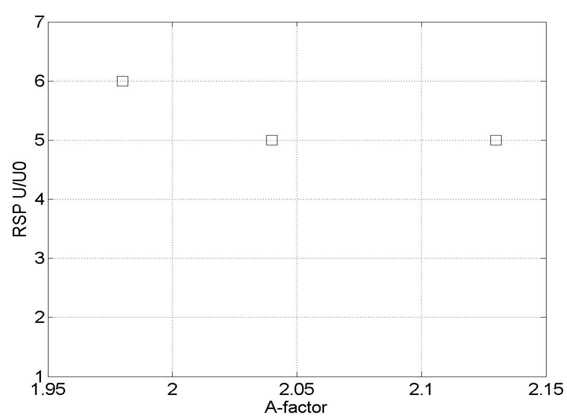

Figure 7: RSP according to IRC-analysis for graphite semi-conducting type

Table 1: Preliminary guide for XLPE cable with strippable or paint and tape semi-conducting material

A-factor	Remark	Action
< 1.5	Good	No action required
1.5 – 2.5	Old	More frequent measurement required
2.5 – 3.0	Critical	Take measure

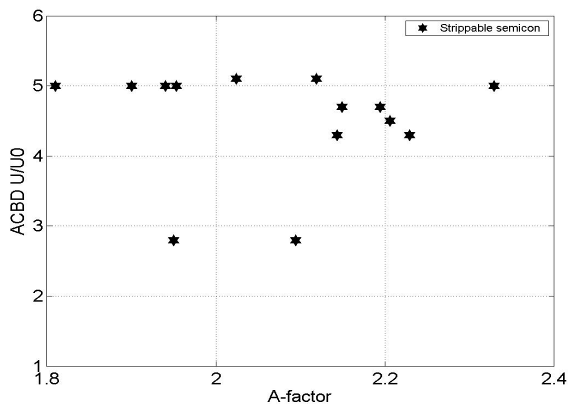

Figure 8: Laboratory measurements of A-factor and ACBD voltage

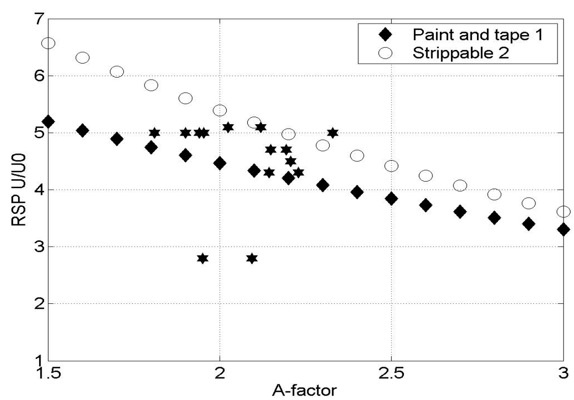

Figure 9: Appreciative curves of A-factor and RSP based on semi-conducting types

Conclusions and future trend

The performance of the IRC test system has been investigated using A-factor as diagnostic criteria. The results of AC breakdown test have showed poor correlation between Empirical ageing factor, A-factor and AC breakdown voltage. However, if semi-conducting material of the cable insulation is known it is possible to get some correlation between A-factor and AC breakdown voltage.

The combination between A-factor and residual strength prognosis gives better correlation. However, more data is expected on cables with graphite and other type of semi-conducting insulation.

What might be of interest is to correlate the water tree length with the AC breakdown voltage. In addition it will be of interest to see the relation between the RSP, A-factor and water tree length. It is anticipated that water tree length that determines the minimum breakdown strength of the insulation is independent of the semi-conducting material. Future work should concentrate in this direction.

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